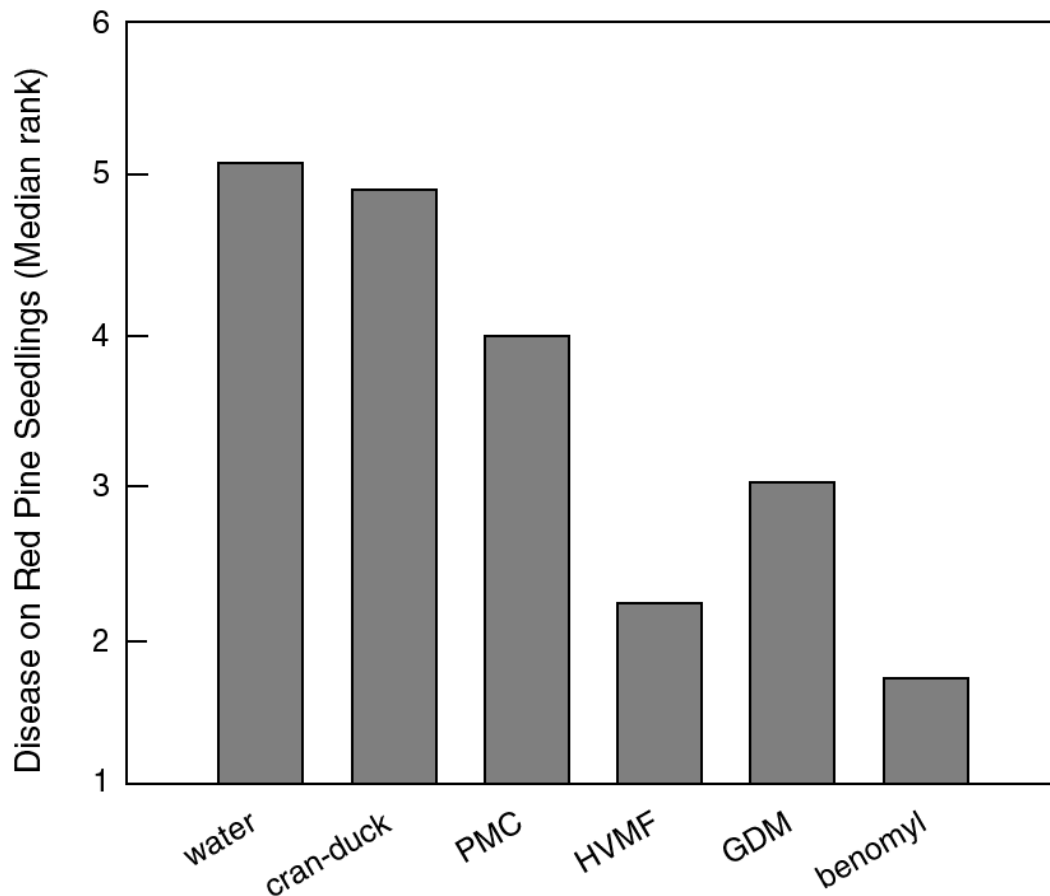


**Figure 38**

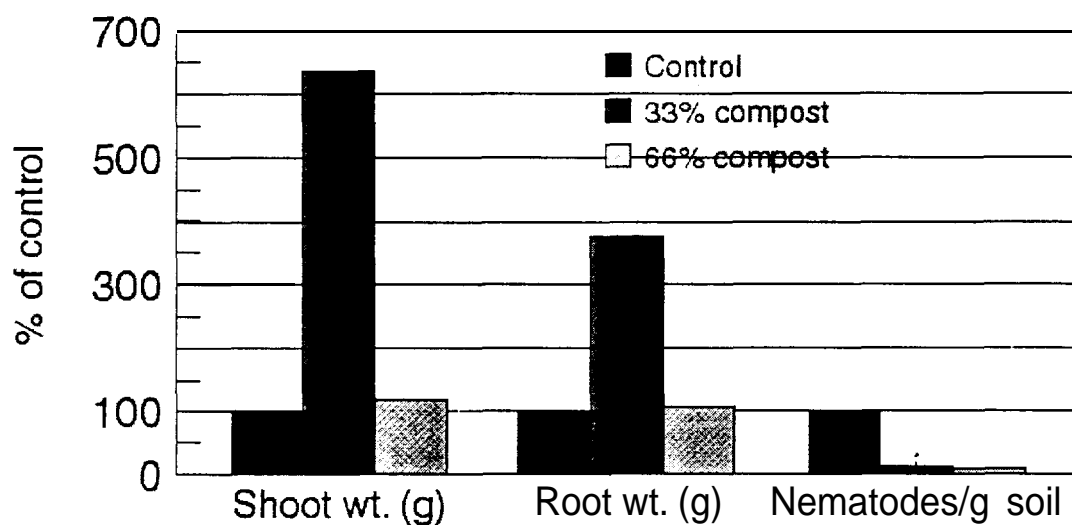
**Influence of Extracts of Spent Mushroom Substrate (PMC, HVMF, and GDM) and a Compost Prepared From Cranberry Waste and Duck Manure on Disease Severity of Red Pine Blight**



Source: Yohalem, 1994 (Figure 5)

Figure 39

Effects of MSW Compost on Green Pepper Growth and Populations of the Root-Parasitic Nematode *Meloidogyne Javanica* in a Pot Study



Source: Marull, 1997 (Table 2)

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## Chapter 6

### Compost-Enhanced Phytoremediation of Contaminated Soil

Phytoremediation is a developing technology in which higher plants and microorganisms associated with plant roots are the active agents for uptake and/or degradation of toxic inorganic and organic compounds in soil and water. This method successfully intercepts nitrate and prevents its transfer from groundwater to surface water. It also is used in a number of applications with organics-contaminated water (Table 9). As indicated in Chapter 4, plants also reduce the erosional transport of contaminated soil when compared to unvegetated material. Given this, phytoremediation provides a straightforward approach to both the degradation and containment of contaminated soil and water, as shown in Figure 40. In this case, contaminated water is stripped of contaminants as it flows past the plant roots, as a result of waste uptake by the plants. Depending on the contaminant, degradation might occur in the rhizosphere (the soil adjacent to plant roots) or within the plant itself. If the compound is not degraded, it will likely volatilize. Regardless of the ultimate fate of the contaminant, once contact with the plant occurs, the water is no longer contaminated. This process might be suitable for soil remediation and/or inexpensive confinement of shallow contaminated water.

Phytoremediation of metal-contaminated soil relies on the ability of plants to accumulate metals at concentrations substantially above those found in the soil in which they grow (Kelly, 1995; Brown, 1994; Brown, 1995; Cunningham, 1995; Cornish, 1995). Since plant uptake requires that metals be in an environmentally mobile form (Schnoor, 1995), the use of compost is likely to be an impediment to successful phytoremediation, as compost immobilizes toxic metals (see Chapter 4 for examples).

**Table 9**  
**Phytoremediation of Contaminated Soil or Water<sup>a</sup>**

Contaminated Material	Contaminants	Results
Water (hydroponic system in laboratory)	Nitrobenzene	Complete uptake from solution
Soil	Trinitrotoluene	Essentially complete treatment
Soil	Trichloroethylene	Enhanced mineralization
Contaminated soil	Pentachlorophenol and phenanthrene	Enhanced mineralization
Soil	Trinitrotoluene	Enhanced degradation

<sup>a</sup> Adapted from Schnoor, 1995.

Numerous reports indicate that plants can take up and degrade toxic organic compounds in soil, while other work indicates microorganisms in the rhizosphere are very competent degraders of soil-borne organics. Rhizosphere microorganisms are able to degrade the herbicide 2,4-dichlorophenoxyacetic acid (2,4-D) much more rapidly than those in root-free soil and convert a higher percentage of carbon in 2,4-D to carbon dioxide, as shown in Figure 41 (Shann, 1994). In contrast, enhanced mineralization of <sup>14</sup>C-labeled pyrene was not found in rhizosphere soil (Schwab, 1994 and Schwab, 1995). These apparently conflicting results are due to the relatively high mobility of 2,4-D in soil as compared to pyrene. As a result of rapid water uptake by plants, desorption of contaminants from soil may be the rate-limiting step for degradation (Schnoor, 1995). Based on the examples shown in Table 9, plants might decrease remediation time, as well as enhance the complete destruction of target compounds. Further work is required to define the characteristics of plants and soil systems before an understanding of the appropriateness of phytoremediation for particular situations can be attained.

Phytoremediation has very large economic advantages over mechanically intensive technologies because plants require little maintenance in comparison to machinery. The following are the major constraints of the method:

- Relatively slow remediation rates. The time until site closure can be years. This constraint means that phytoremediation cannot be the method of choice when rapid site closure is a necessity.
- Lack of information about the fate of compounds in planted soil. Losses of volatile  $^{14}\text{C}$  from  $^{14}\text{C}$ -labeled naphthalene are about 50 percent higher in planted soil than in unplanted soil (Watkins, 1994). Poor recovery is probably the result of inefficient capture of volatile organics and/or carbon dioxide and can be solved by the development of better test systems. Chapter 2 details the issue of whether partial degradation of xenobiotics, followed by conversion of metabolites into immobile forms, is a sufficient remedy for contamination. This same issue arises with phytoremediation, because immobilization of carbon from xenobiotics in conjugated forms is promoted in planted systems. The results, presented in Figure 42, indicate that studies of the fate of xenobiotic residues when they enter soil would be appropriate. Because of the complexity of plants, microorganisms, and soil systems and the uncertainties of chemical behavior in these systems, further research is necessary before this method can be employed on a large scale.
- Difficulties in establishing plants in toxic, contaminated matrices, and in compacted and barren materials that are not conducive to plant growth. This constraint can be overcome by the addition of compost. A small body of research indicates that compost can reduce toxicity of contaminated soil (probably through the adsorption of the toxic compounds to organic matter in the compost). Figure 43 compares the growth of herbicide-sensitive weed species when grown in contaminated material from an agrichemical retail site. In the absence of compost, little weed growth occurs, but addition of compost detoxifies the soil and good weed growth occurs. In this case, plant growth also accelerated decontamination when compared with soil without compost addition, as shown in Table 10.

The amount of compost needed to achieve beneficial effects varies with the project goals. For example, 20 percent w/w compost is sufficient to maximize plant growth in herbicide-contaminated soil (Figure 44), but 40 percent compost is needed to accelerate herbicide degradation in the same soil (Figure 45). The decrease in remediation time for relatively degradable compounds like metolachlor strongly suggests that phytoremediation—if healthy and vigorous plants can be

established—has considerable potential for enhancing bioremediation activities, particularly in situations such as urban brownfields (Chapter 4), where cost and time are important components in choosing a remediation method.

**Table 10**  
**Effects of Mix Composition and Planting on Pesticide Degradation,**  
**Following 40 Days of Plant Growth<sup>a</sup>**

Mixture	Treatment	Trifluralin	Metolachlor	Pendimethalin
		mg kg <sup>-1</sup> soil		
Initial concentration	None	2.2 ± 0.9	3.0 ± 0.2	11.8 ± 5.1
100% contamination	Planted	0.80 ± 0.82 (0.27) <sup>(b)</sup>	3.4 ± 5.0 (0.25)	1.6 ± 0.4 (0.02)
100% contamination	Not planted	0.48 ± 0.77 (0.77)	0.99 ± 1.4 (0.25)	1.8 ± 0.4 (0.02)
50:50 soil	Planted	nd <sup>(c)</sup>	nd	0.5 ± 0.6 (0.01)
50:50 soil	Not planted	0.52 ± 0.53 (0.07)	0.18 ± 0.16 (<0.001)	1.0 ± 0.2 (0.02)
50:50 compost	Planted	0.36 ± 0.33 (0.02)	nd	1.5 ± 0.6 (0.02)
50:50 compost	Not planted	0.44 ± 0.69 (0.08)	2.8 ± 3.4 (0.29)	2.6 ± 3.4 (0.12)

<sup>a</sup> Values are means ± standard deviations of duplicate extractions of four replications per treatment.

<sup>b</sup> Values in parentheses indicate the probability that the values are less than experiences from dilution alone (based on a one-tailed t-test for means of unequal variance).

<sup>c</sup> nd = not detected.

Source: Liu, 1995

Figure 40

Potential Fates of Xenobiotics in Planted Soils

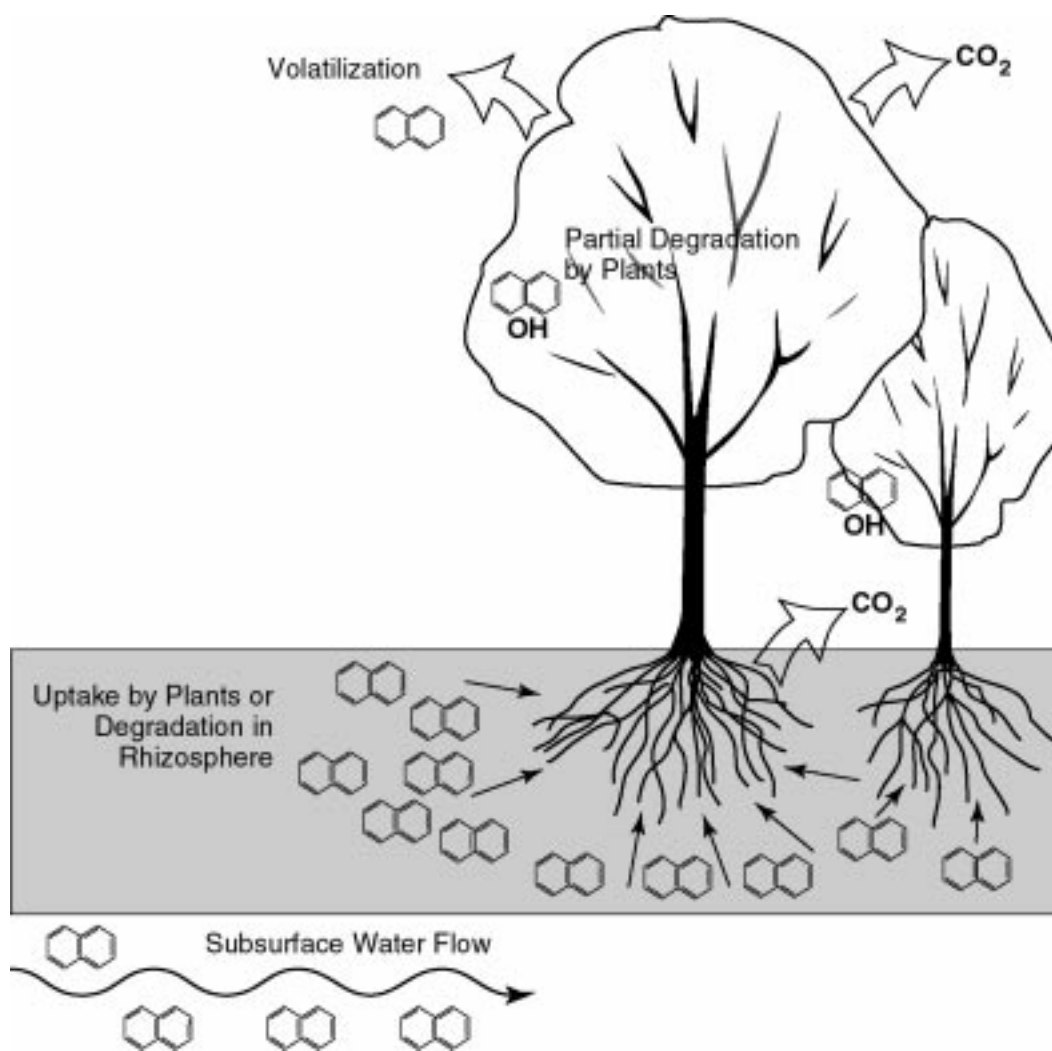
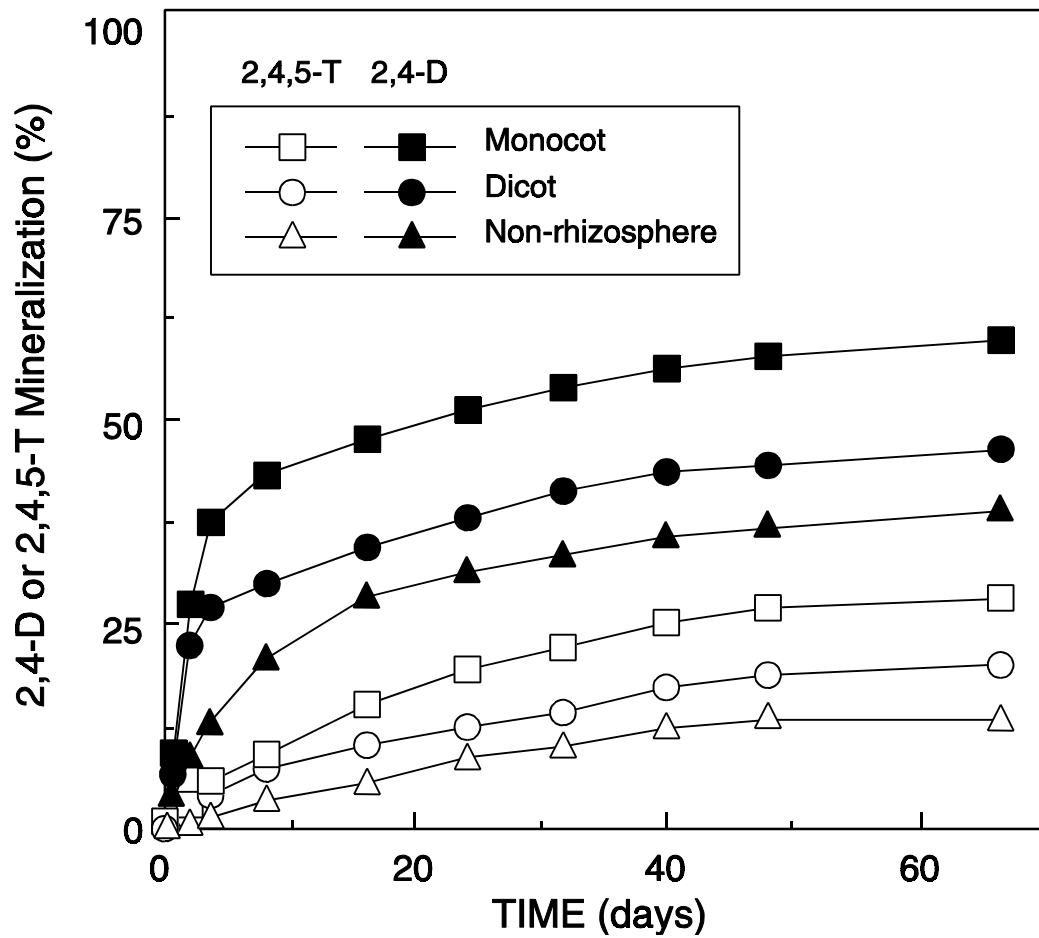


Figure 41

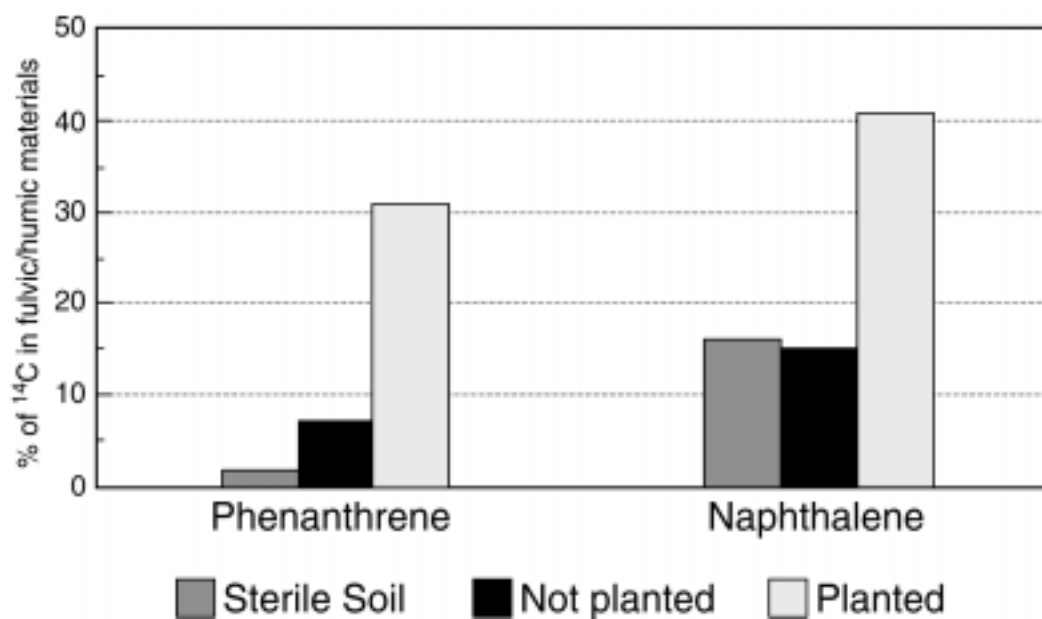
Enhanced Degradation Rates and Mineralization Percentage in Rhizosphere Versus Non-rhizosphere Soil



Source: Shann, 1994

**Figure 42**

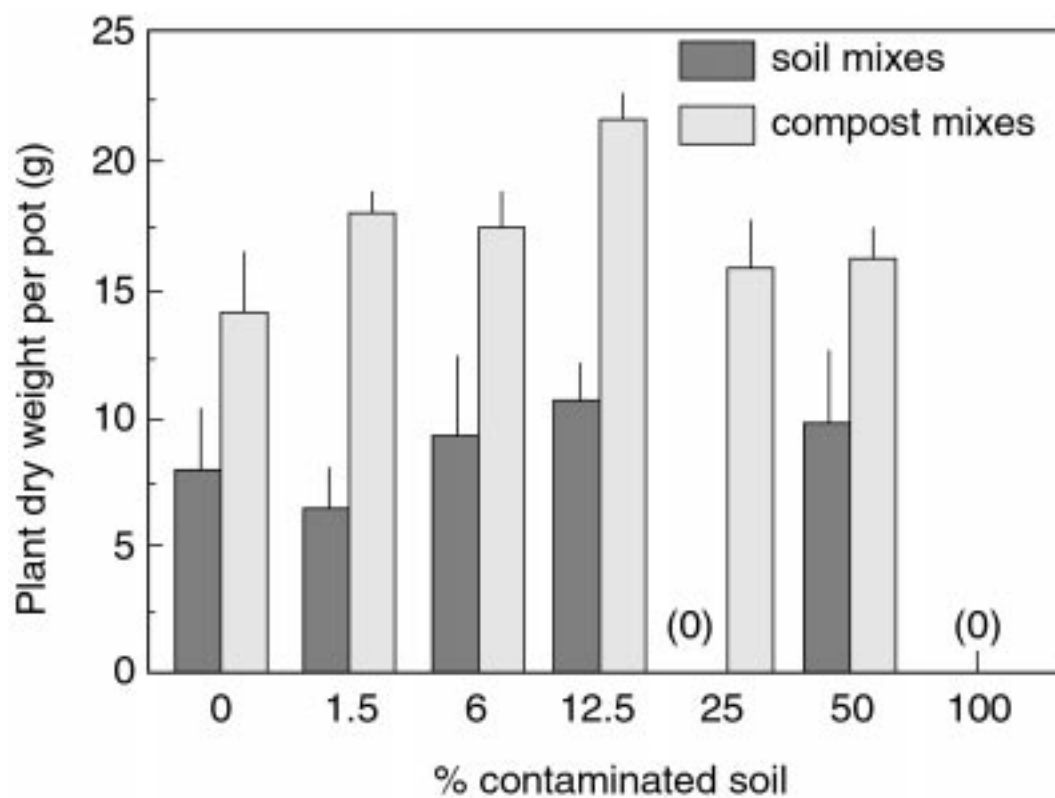
**Influence of Plants on Immobilization of  $^{14}\text{C}$  From Aromatic Compounds in Soil**



Source: Walton, 1994 (Table 1)

Figure 43

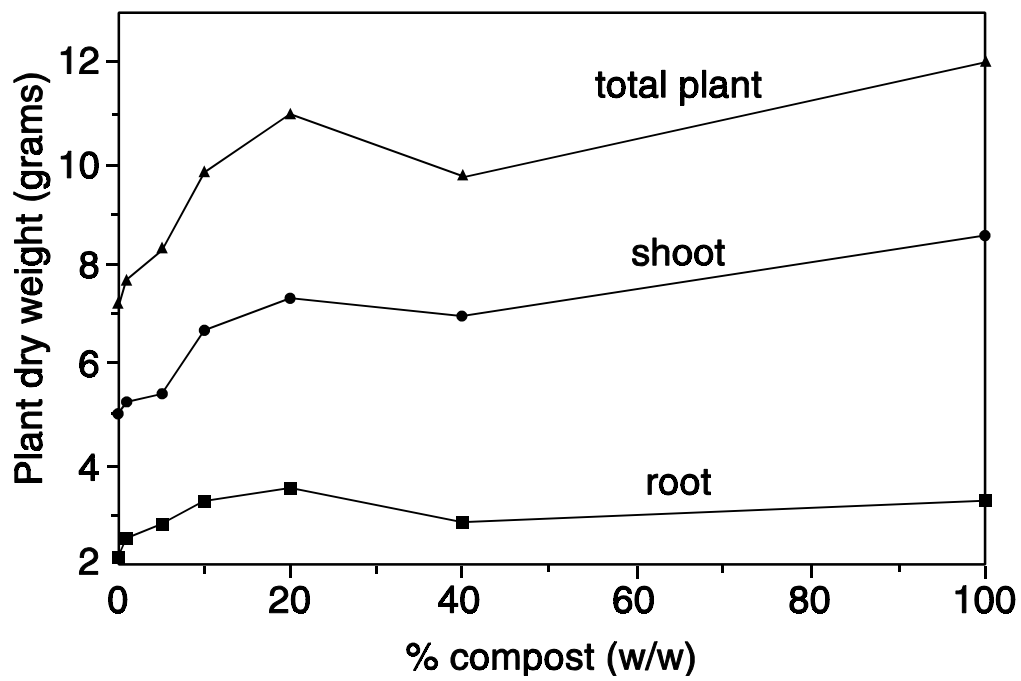
Reduction of Phytotoxicity in Herbicide-Contaminated Soil by Compost



Source: Cole, 1994

Figure 44

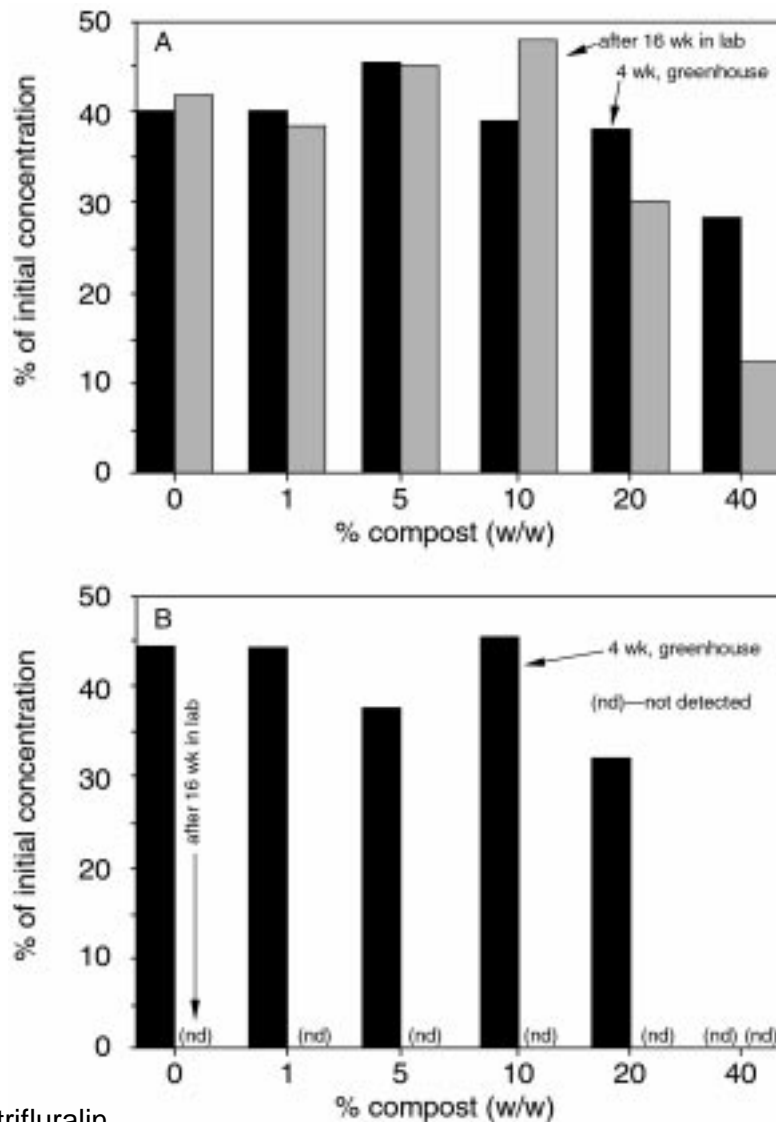
Effect of Amount of Compost Added on Plant Growth in Contaminated Soil



Source: Liu, 1996

Figure 45

Effect of Amount of Compost Added on Rates of Pesticide Degradation in Contaminated Soil



A=Degradation of trifluralin  
B=Degradation of metolachlor

Source: Liu, 1996

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## Chapter 7

### Development of Special-Purpose (Customized) Composts

The majority of the research described in this report was conducted with little discrimination among composts, other than their ready availability. Where different types or ages of compost were compared, substantial differences were found in the ability of the compost to accelerate degradation of organic compounds (Chapter 2) and in disease-suppressive ability (Chapter 5). Compost maturity is certainly a factor in revegetation studies, since numerous researchers have reported that immature composts are phytotoxic. The relatively high success rate for various projects, in spite of the apparently random selection of compost, strongly suggests that particular activities of compost can be enhanced, thereby increasing the effectiveness of the compost. Composts of this type are referred to as "tailor-made" or "designer" composts. The term "special-purpose compost" is used in this chapter to describe composts that are specially treated during production to enhance specific attributes, produced from particular feedstocks to increase activity, to which specific microorganisms have been added, and to which constituents other than organic feedstocks have been added.

In addition to relatively random selection of compost for their research, most researchers conducted their studies with unamended compost. Substantial literature indicates minerals play a major role in controlling the environmental fate and availability of both organic and inorganic components (Hassett, 1989; Ziekle, 1989; Scow, 1993; Dixon, 1977). Little of this work, however, has been applied to improving compost. This chapter describes several cases where the performance of compost was significantly enhanced by special treatment.

The special treatment of feedstock has the potential to improve compost's metal removal capabilities (Chang, 1995). A recent study conducted with sewage sludge serves as a precedent for potential improvement of metal-binding activity of biosolids compost. In the study, various additions were made to a sewage sludge culture. Copper-binding—but not cadmium-binding—activity varied substantially among the initial cultures (Figure 46). In addition, particular treatments significantly increased the absorption capacity of the cultures for particular metals. It is likely that the same type of process could be used to develop biosolids compost for the types of applications described in Chapter 4.

The metal-binding capacity of composts can be improved by the addition of inorganic materials. For example, the addition of soluble iron and/or phosphate salts to compost increases lead immobilization as a result of forming complex lead-iron-phosphate minerals. Similarly, research by several investigators indicates that some clay minerals interact with lead to form lead-containing minerals in which the bioavailability of the lead is remarkably low (Ryan, no date). Addition of such clays may enhance the ability of compost to decrease lead availability. This suggestion raises the issue of whether immobilization of metals is a sufficient endpoint for remediation (see Chapter 4). Nevertheless, decreased lead availability provides an illustration of the potential for improving the desirable characteristics of compost.

One promising technique in bioremediation is the establishment of desirable microorganisms in soil by adding them as an inoculant (Brown, 1993). This process is referred to as "bioaugmentation." One of the common problems with bioaugmentation is the difficulty in establishing exogenous microorganisms in the contaminated soil (Alexander, 1994; Van Veen, 1997). The addition of microorganisms in compost often results in a 2- to 15-fold increase in bacterial and fungal populations for at least 6 weeks after adding the compost to contaminated soil (Cole, 1996). It appears from these results that the compost protects organisms from predation and other problems that ordinarily result in their loss when added to soil. If this statement is true, then production of composts containing particularly good degraders of pollutants could be a viable approach to microbial introductions into soil.

Disease-suppressive organisms isolated from compost can be added to compost at high populations (Hoitink, 1990). The resulting compost has better disease-suppressing activity than uninoculated compost (Hoitink, 1993). In addition, compost with more consistent disease suppression can be produced by isolating antagonistic organisms from compost, propagating them in the laboratory, and adding them back to raw materials prior to composting (Nakasaki, 1996). Both of these examples support the suggestion that compost used for bioremediation can be improved in the same manner.

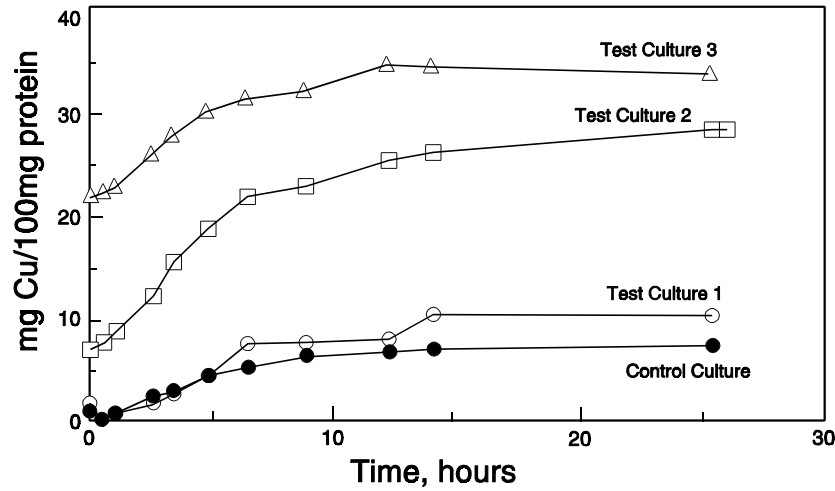
Several studies in Chapter 3 demonstrate that compost biofilter performance improves substantially after an extended exposure time to contaminated air. This behavior is strongly suggestive of selection for a highly competent population of degrading organisms in the compost. The poor performance of the filters initially might be attributed to the lack of appropriate organisms in sufficient numbers in the starting material. If this interpretation is

correct, then isolation of appropriate microorganisms from effective biofilters and introduction into ineffective biofilters may be a rapid method for improving filter performance.

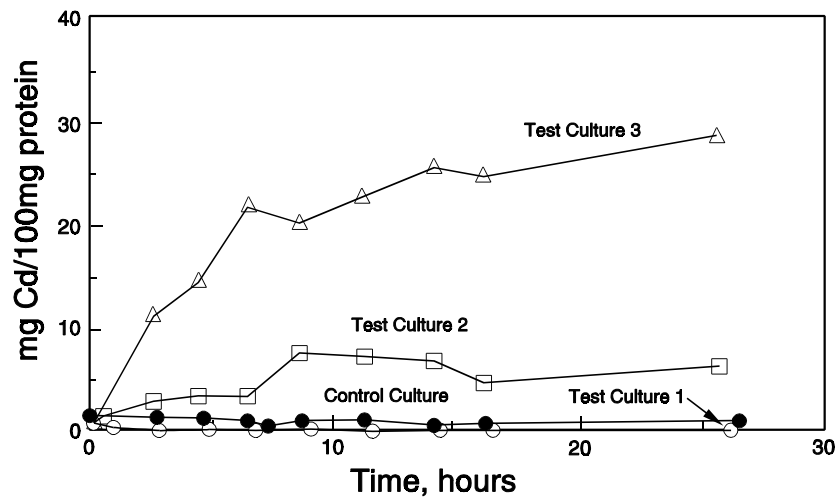
Several references in Chapter 1 demonstrate that microbial populations are large and that their biodiversity is high during the composting process and in mature compost. Since the environmental conditions during composting are radically different from those experienced by organisms in most natural environments, it is possible that compost-derived organisms might have abilities not found in the microbial populations of soil and water. For this reason, further studies on microbial ecology of compost are likely to have beneficial effects, not only for the composting industry but also for uses of compost-based materials.

**Figure 46**

**Enhancement of Metal-Binding Capacity of Sewage Sludge Cultures by Nutrient Amendment and Prior Exposure to Subtoxic Concentrations of Copper and Cadmium**



Effect of culture acclimation and stimulation of copper uptake efficiencies.



Effect of culture acclimation and stimulation of cadmium uptake efficiencies.

There is substantial diversity among organisms in terms of their ability to accumulate metals. Given the diversity of organisms in different composts and the wide range of composition among composts produced from different raw materials (see Chapter 1), it is likely that substantial variations in metal-binding ability will be found among different composted materials.

Source: Chang, 1995

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